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SUBJECT: Review of EVA/IVA Life Support
Equipment for AAP - ML Action
Item 478 - Case 620

DATE: December 24, 1968

FROM: W. W. Hough

ABSTRACT

A small, chest-mounted Pressure Control Unit (PCU) plus an umbilical to spacecraft systems appears to be the optimum portable life support system for all extravehicular and suited intravehicular activities in AAP. During these EVA and IVA operations, the metabolic heat generated by the astronaut must be removed from the spacesuit by an active system. All existing heat rejection sources that are small enough to be incorporated in a self-contained portable life support system depend on water evaporation or sublimation, and will not operate in a pressurized environment.

As most IVA in AAP is performed in a 5 psia environment, the liquid cooling garment, which is in effect a cold-plate for the body, must be connected by a water umbilical to a spacecraft system which rejects heat to space. Since an umbilical is required for IVA cooling, a high pressure oxygen supply line has been added to avoid recharge requirements. High pressure oxygen is already available in the AAP-2 Airlock for module pressurization and for experiments. The PCU regulates this oxygen to suit pressure, and vents the return. A minimum flow rate that maintains CO₂ partial pressure in the suit at an acceptable level is used. Vented oxygen is not lost, as it replenishes the cabin. Communications and biomedical data are transmitted through an electrical umbilical.

For EVA from the Airlock, it is a simple extension to provide an emergency oxygen supply for the PCU to guard against umbilical failure, and connect the umbilical to the same outlets provided for suited IVA. Use of the PCU and umbilical is particularly attractive in view of the demonstrated complexity of maneuvering through the AM trusses while wearing a backpack of the Apollo Portable Life Support System (PLSS) configuration. No weight penalty is incurred with the PCU open-loop ventilation system because of the higher fixed weight of the PLSS.

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ABSTRACT - continued

For ATM EVA from the LM-A, umbilical management is more troublesome and the backpack is less cumbersome than in the case of EVA from the Airlock. However, use of the Apollo PLSS would result in restrictions on time and/or work rates below the design levels for ATM EVA. To avoid such restrictions, the PLSS would have to be modified or replaced by the next generation system, the Portable Environmental Control System. The cost of either backpack and its reservice systems will probably run at least three million dollars more than the two million dollar cost of the umbilical support system baselined for the LM-A. Besides the cost advantage, an umbilical/PCU EVA system offers stowage advantages and reduces donning and checkout time. It requires no reservicing and, unlike the self-contained systems, provides cooling before the cabin is depressurized. Weight of oxygen lost roughly balances the weight of backpack hardware and supplies.

The concept of using an umbilical supported by another module, which is pulled through the LM cabin to the EVA astronauts, is not attractive. It is doubtful that any money could be saved, and operational problems would be increased.

A system other than the umbilical/PCU would not be recommended for ATM EVA unless the only way to solve the umbilical management problem is to eliminate it. Before this problem is solved, it must be defined, and therefore it is recommended that the neutral buoyancy test program begin at MSFC as soon as possible.

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MEMORANDUM FOR FILE

INTRODUCTION

The broad definitions of extravehicular activity (EVA) and intravehicular activity (IVA) agreed to by the OMSF Ad-Hoc EVA Working Group are:

EVA: Activity performed in space by an astronaut
"external" to the space vehicle.

IVA: Activity performed in space by an astronaut
"internal" to the space vehicle.

Since the ambient environment during EVA is a vacuum, the astronaut must be housed in a pressurized suit. There are three modes of operation possible in IVA:

Pressurized Suit,

The astronaut is suited and the suit is pressurized above the local ambient. This mode must be used when the ambient is a vacuum (e.g., EVA preparation in the Airlock), and will also be used during AAP maneuvering experiments when the ambient is the nominal 5 psia.

Vented Suit,

The astronaut is suited but the suit pressure is equal to the local ambient. This is the nominal AAP mode for entering the AM/MDA from the CM and the OWS for the AM. Ambient pressure must be greater than 3 psia.

Shirtsleeve,

The astronaut is not suited, and is dependent on the ambient environment for life support.

This review is concerned only with equipment that must meet the life support requirements of a suited astronaut during relatively short periods of high metabolic activity. Equipment for the shirtsleeve mode of IVA, which is the dominant mode in terms of time, is not considered. Existing Apollo Command Module equipment, which supports suited astronauts during periods of low metabolic activity, is briefly mentioned.

REQUIREMENTS

The basic life support requirements of an astronaut in a space suit are:

1. pressurization
2. oxygen supply for respiration
3. removal of carbon dioxide and other contaminants
4. thermal control - temperature and humidity.

The metabolic rate (defined as the total energy output of the man per unit time), together with type of fuel being oxidized in metabolism, serve to determine the quantity of oxygen used and the quantity of CO_2 produced. The composition of the diet (fuel being oxidized) determines the respiratory quotient (RQ), which is the ratio of the volume of carbon dioxide produced to the volume of oxygen used. It ranges from .707 for a pure fat diet to 1.00 for a pure carbohydrate diet; an approximate value for the mixed diet of an astronaut is 0.84. The RQ can be used to determine the metabolic energy output for a given oxygen input. The oxidation of a fuel that results in an RQ of .84 by one liter of dry oxygen at standard temperature and pressure yields 4.85 kcal of energy. This is equivalent to 6109.9 BTU energy output per pound of oxygen consumed. The weight of carbon dioxide produced per pound of oxygen consumed is determined by multiplying the RQ by the ratio of molecular weights, which yields 1.155 at an RQ of 0.84.

Most of the astronaut's energy output is released as heat, as the useful external work performed in a pressurized spacesuit is a very small percentage of the total energy, and will most likely never exceed 5%. The normal assumption that the total energy output of a suited astronaut is in the form of metabolic heat is therefore only slightly conservative.* Water vapor released to the suit atmosphere by insensible perspiration

*The energy needed for internal work, such as pumping by the heart or flexure of muscles, is converted to and leaves the body as heat. The percentage of the total energy output needed for external work on the air during respiration is negligible. The majority of the external work performed while in a pressurized suit will be done on the suit itself and, because of internal volume change, on the gas within it. Much of this work will become heat through frictional losses of the suit.

and evaporation from the lungs is a strong function of metabolic rate. The evaporation of sensible perspiration (sweat) will also increase the humidity, but the amount of sweating will be kept at comfortable levels by an active cooling system.

We have seen how the astronaut's metabolic rate quantitatively effects his life support requirements. To calculate these quantities, we need estimates of total metabolic rates during periods of suited IVA and EVA. The expected metabolic rate for a relaxed astronaut is approximately 400 BTU/hr. Mild activity, such as systems monitoring while seated in a CM couch, will increase the metabolic rate to between 500 and 600 BTU/hr. More strenuous activities, such as transfer within the Cluster in a vented suit, will require energy at rates between 1000 and 1500 BTU/hr. Very strenuous activities, such as IVA or EVA tasks in a pressurized suit in zero-g, will require peak metabolic rates of 2000 to 3000 BTU/hr.

At high metabolic loads, a man can go into oxygen-debt, where stored oxygen is drawn from his system. This oxygen will be made up during periods of rest. Since rest periods are provided during EVA and IVA in AAP, it is assumed that there is no net loss of stored oxygen over the whole activity period. The requirements vs. capability problems are worked as steady state problems, using only a respiratory quotient of 0.84 and the average metabolic rate.

A7L SPACESUIT

The Apollo Applications Program will use the Apollo A7L spacesuit, which is manufactured by the International Latex Corporation. The pressure garment assembly (PGA) provides the mobile life support chamber. The helmet will be of the visor type. When pressurized, the suit will be maintained at 3.7 to 3.9 psig. Oxygen supply and carbon dioxide removal requirements are met by ventilating the suit with oxygen. Ventilation also provides humidity control by removing water vapor, and some cooling by both convection and sweat evaporation. The A7L PGA has two sets of inlet and outlet oxygen hose connectors located on the left and right rib cage areas. Ventilating oxygen input will be distributed equally between the helmet and the suit when the metabolic rate is low and ventilation is the only means of active cooling. This mode is used when support is by the suit circuit of the CM environmental control system (ECS). At higher metabolic rate, gas cooling is inefficient and uncomfortable. The ventilation rate must be high, which influences the size and weight of ECS components, and cooling depends on evaporation of uncomfortable amounts of sensible perspiration.

Experience with insufficient gas cooling in Gemini EVA, and technological advances in other means of active cooling, have led to the development of a liquid cooling garment (LCG) for Apollo EVA. The LCG is in effect a cold-plate for the body, and is worn as an undergarment when metabolic activities will be high. The PGA has water inlet and outlet ports in the upper-left chest area which provide the interface between the LCG and an external coolant pumping system and heat exchanger. When the LCG is operating, all ventilating oxygen is directed first to the helmet, and then through the suit. In this mode, most of the ventilating oxygen is effective in removing CO_2 from the helmet, and as cooling no longer depends on ventilation rate, the rate requirement is decreased by more than a factor of two. This is important if the support system is portable, particularly if the ventilation system is open-loop (i.e., all ventilating oxygen passed through the suit is lost).

A7L spacesuit includes a communication soft hat (CSH), which has two microphones and two earphones for voice communications. The biomedical belt (BMB) and sensors for measuring heartbeat and respiration rate are also worn inside the PGA. An electrical connector, which services both the CSH and the BMB, is mounted in the upper-right chest area of the PGA. When the spacesuit will be used in EVA, the PGA is covered with an integrated thermal-meteoroid garment. If it will be worn inside the spacecraft only, it is covered with an intravehicular cover, which minimizes PGA wear. When metabolic rates are low and the suit is being ventilated by the CM ECS, the LCG is replaced by the constant wear garment.

CM ECS SUIT CIRCUIT

The CM ECS supplies low pressure oxygen to the PGA at a relatively high rate. There is no equipment in the CM that will interface with the LCG, and as we've seen, ventilation is the only means of active cooling. The return gas is passed through a CO_2 and odor absorber assembly and then through the suit heat exchanger where it is cooled and water vapor is condensed and removed. The dry, cool gas is replenished with oxygen and returned to the suit. The portion of the total ventilating gas that purges the helmet (50%) is more than sufficient to maintain the CO_2 partial pressure below acceptable levels, particularly at the expected low metabolic rate of a crewman in the CM couch. The suit and suit circuit of the CM ECS are an example of a closed-loop oxygen system.

The CM ECS cannot be used for ventilation if there is a large separation between the system and the suit. The suit circuit compressors cannot supply a pressure difference sufficient to maintain the suit pressure and ventilation rate (even with active cooling by the LCG) at proper levels because of losses in the low-pressure supply and return hoses. Because AAP EVA and suited IVA activities, which generally will require high metabolic output, will be performed at relatively great distances for the CM, a portable ventilation system is required.

PORTABLE LIFE SUPPORT SYSTEMS

Portable life support systems for use with a space-suit can range from totally self-contained units to simply interface connections between the spacecraft and the suit. The latter must be connected to the spacecraft by an umbilical. High pressure oxygen, either self-contained or spacecraft supplied, is regulated to the suit pressure for ventilation. In a closed-loop system, return oxygen is processed for CO₂ and water vapor removal, cooled, replenished with oxygen for respiration and suit leakage, and recirculated to the suit. In an open-loop system, return oxygen is vented. During EVA, all vented oxygen is lost. Therefore, in an open-loop system, it is imperative that the ventilation rate be kept at the minimum level that provides just CO₂ and water vapor washout. It is also desirable to keep the ventilation rate low in a closed-loop system, as lower rates mean smaller circulation systems. For these reasons, as well as the increased cooling efficiency and greater comfort, all suited EVA and IVA activities (except in the CM) in AAP will use the liquid cooling garment rather than ventilation cooling for rejection of the majority of metabolic heat.*

* The Gemini Extravehicular Life Support System (ELSS) did not use a liquid cooling garment, primarily because this technique was beyond the state-of-the-art at the time. Instead, a rather ingenious method of ventilation cooling was used. The ELSS was a semi open-loop system, in which fresh high-pressure oxygen was supplied at a rate equal to the CO₂ washout requirement. It was supplied by an ejector rather than a regulator, and the high velocity oxygen leaving the ejector mixed with the residual gas in the supply line, thus propelling the total mixture through the suit. After an amount of gas equal to that supplied through the ejector was vented overboard, the oxygen was cooled in an evaporative heat exchanger and returned to the suit past the ejector. However, unexpected metabolic loads during Gemini EVA substantially exceeded the cooling capacity of the ELSS, and one of the recommendations of that Program was: "In future Extravehicular Life Support Systems, consideration should be given to cooling systems with greater heat removal capacity than the gaseous cooling systems used in the Gemini Program."

Circulating coolant is heated in the LCG and then passed through a liquid-to-liquid heat exchanger, where the metabolic heat is transferred to another liquid. This second liquid can be the coolant in the spacecraft ECS radiator network, or water which is evaporated or sublimated to vacuum. Because of the large radiator surface that would be required, only water boilers or sublimators can be used in self-contained portable life support systems. These components use the heat from the LCG loop to vaporize (sublimate) water, and must be operated at pressure near vacuum to work as designed. The temperature of the water being vaporized (sublimated) must be less than the LCG inlet temperature for heat transfer to occur in the proper direction, and the saturated vapor pressure of water at low temperature is very low (at 45°F, the vapor pressure of water is less than 0.15 psia). It is therefore not possible to use a portable, self-contained LCG support system for suited IVA in a pressurized environment. This is true for both pressurized and vented suit conditions. For suited IVA in a pressurized environment, the LCG must be supported through an umbilical by a spacecraft system that rejects heat to space.

SELECTION OF AAP IVA SYSTEM

Both pressurized and vented suit modes of IVA in a pressurized environment are planned for AAP. The only nominal pressurized IVA in a vacuum environment is associated with EVA activities, and is properly included in that category. However, off-nominal conditions, such as the MDA failing to pressurize before an astronaut enters it from the CM, must be provided for. As the LCG will be used in all cases (except IVA in the CM) for the rejection of the majority of metabolic heat, all ventilating oxygen will be directed to the helmet whenever the helmet visor is closed. The assumed mixing efficiency of incoming oxygen to respired CO₂ in the helmet is approximately 75% -- that is, 75% of the ventilating oxygen is effective in washing out CO₂. Figure 1 gives the oxygen volumetric flow requirement to maintain the maximum nominal CO₂ partial pressure of 7.6 mmHg, for 75% and 100% mixing efficiencies, vs. metabolic rate. The RQ is taken as 0.84 and the temperature as 70°F. The required mass flow rate of ventilating oxygen is given vs. metabolic rate in Figure 2 for the two mixing efficiencies and for the three nominal total suit pressure conditions. These conditions are: pressurized suit in vacuum environment, $P_t = 3.9$ psia; vented suit in pressurized environment, but with visor closed, $P_t = 5.0$ psia, and pressurized suit in a pressurized environment, $P_t = 8.9$ psia. The 75% helmet mixing efficiency can be improved by concentrating the inflow around the oral-nasal area by a small mask. This will yield almost 100% mixing, and such a mask will be used when the suit pressure is 8.9 psia to minimize the mass flow rate requirement to the suit. For example, during the pressurized

suit phases of the M509 Astronaut Maneuvering Experiment, when the expected average metabolic rate is approximately 1600 BTU/hr, the mass flow rate requirement to the suit will be cut from 17.4 to 13 pounds/hour by use of the mask.

The question of whether high pressure oxygen should be self-contained in, or umbilically supplied to, the portable life support system is easily answered for the case of IVA. The liquid cooling garment must be supported by an umbilical, and the problem of umbilical management in IVA exists in either case. High pressure oxygen must be supplied by the CM-SM to the forward Airlock Module section, the Airlock itself, and the Workshop and regulated for pressurization of these volumes and for the conduction of some experiments. Since the oxygen supply is there, and since a water umbilical is required, the addition of an open-loop oxygen supply line to the umbilical results in the simplest and smallest portable life support system possible. The same argument leads to the conclusion that a cable for voice and biomedical data transmission should be included in the umbilical, rather than using a radio transmitter/receiver system.

Oxygen will flow only when the helmet visor is closed, and during IVA in a pressurized environment, this will be the nominal condition only for brief experiment periods in the voluminous Workshop. The vented oxygen from the open-loop system is not necessarily lost because it makes up for cabin leakage. Oxygen will be lost only if the upper cabin pressure limit is reached. To increase the cabin pressure from the nominal 5 psia to the relief pressure of 6 psia, a net addition of about 90 pounds of oxygen will be required. At the 12.3 lbs/hour net rate of oxygen addition (assuming 13 lbs/hr supply to one 8.9 psia suit with mask less approximately 0.7 lb/hr leakage), it will take 7 hours to reach the upper pressure limit. As pressurized suit experiment periods are measured in minutes, it is not expected that any oxygen will be lost due to the open-loop nature of the oxygen ventilation system.

The portable life support system that will be used as the interface between the oxygen umbilical and the spacesuit is called the Pressure Control Unit (PCU). It is worn as a chest pack. Its dimensions are 6" x 10" x 12", and it weighs 12 pounds. It includes a demand regulator which reduces the umbilical O₂ pressure of 120 psia to the suit pressure, a suit pressure regulator which maintains the suit pressure and through which return gas is vented, a flow rate selector valve, and pressure, temperature and flow sensors. There are two oxygen umbilical quick disconnects which permit switching from one umbilical to another without interruption of ventilation. The LCG water supply and return umbilical hoses connect directly to the suit; there is no water interface in the PCU.

Two liquid cooling garment support loops have been incorporated in the Airlock Module. The liquid-to-liquid heat exchangers connect the LCG water loops directly to the AM-MDA coolant loop, and final heat rejection to space is through the radiators on the MDA and structural transition section (STS). The two loops have a total heat-rejection capability of 4000 BTU/hr, and can be split 3000/1000. Service connections to the umbilical are provided in both the forward Airlock Module compartment and in the Airlock itself. As there is no LCG support section in the CM, the first thing that must be done during initial entry to the MDA is connect a water umbilical from the forward AM compartment to the suit. The service connections in the Airlock are used for Workshop activation.

The Airlock Module high pressure oxygen system regulates the 900 psia O₂ delivered by the CM-SM to 120 psia for both module pressurization and suit ventilation requirements. Accumulator tanks provide for peak flow requirements. Umbilical service connections are provided adjacent to the water connections in both the forward AM compartment and the Airlock. An IVA oxygen system, which provides 120 psia O₂ to a single umbilical, has been added to the CM. This system will be used for initial MDA entry until the umbilical can be connected to the AM oxygen and water service connections.

SELECTION OF AIRLOCK EVA SYSTEM

Zero-g aircraft simulations of EVA from the Airlock using the self-contained Apollo portable life support system, which is called just that and abbreviated PLSS, have demonstrated that it is almost impossible to maneuver through the Airlock and the AM truss area while wearing it. The PLSS is a backpack, whose dimensions are 26" x 17.84" x 10.5", and it weighs 86 pounds. Other characteristics of the PLSS are given in the next Section on systems for ATM EVA in which the operational problem does not eliminate it from consideration.

Since the Airlock is equipped with all the components and connections needed to support a umbilical EVA, the PCU has been selected as the portable system. Similar (to the above) zero-g simulations have demonstrated that umbilical management is not particularly troublesome during EVA from the Airlock - this is a function of the geometry surrounding the path traversed.

Over 100 pounds of oxygen are lost by open-loop ventilation of two men doing two three-hour EVA's, assuming their combined average metabolic rate is 2000 BTU/man-hour and that the helmet mixing efficiency is 75%.* This is less than the weight of two PLSS's.

* From Figure 2, read 9 lb/hr flow at 3.9 psia for a metabolic rate of 2000 BTU/hr; 9 lb/man-hr x 2 men x 3 hr/EVA x .2 EVA = 108 lbs.

For EVA, an Emergency Oxygen Pack (EOP) will be worn for the contingency of umbilical failure. The EOP supply will maintain the normal flow (9 lbs/hour) for 30 minutes. It is a leg mounted unit, weighs approximately 10 pounds, and carries about 4-1/2 pounds of oxygen at 7500 psia.* It is connected to the PCU at a third quick disconnect port. The PCU will automatically switch to the EOP if the umbilical fails, and includes a heater to warm the incoming oxygen. If the water umbilical also fails, the flow can be increased to provide more ventilation cooling, but the duration capability of the EOP is consequently decreased.

It is clear that the umbilical and PCU, with backup by the EOP, is the proper selection of the support system for EVA from the Airlock. The fact that the same spacecraft and portable systems are used for both EVA and suited IVA eliminate some stowage weight and volume problems and lead to the least complex total configuration.

SELECTION OF LM-ATM EVA SYSTEM

In the ATM mission, EVA for film exchange and recovery is essential in accomplishing primary mission objectives. The ATM mission can be performed coupled with the Workshop, or in a decoupled mode with the LM-ATM docked to the AAP-3 CM-SM. In the decoupled mission, the Airlock is not available and EVA must be performed through the side LM hatch using the cabin as an airlock. This mode is also desirable in the coupled mission, as the distances to be traversed are shorter and egress/ingress problems are diminished.

The use of a self-contained backpack, the PLSS, for EVA from the LM is not immediately ruled out from operational consideration as it is in the case of EVA from the Airlock. In fact, it might have some operational advantages because umbilical management around the ATM outriggers does appear to be a problem. Some crew members who have attempted zero-g aircraft simulations of umbilical ATM EVA have had trouble with the umbilical, and believe that a self-contained life support system plus a short tether that could be attached at various points on the LM-ATM would be preferable from their viewpoint. Another possible advantage of a self-contained portable life support system is that modifications to the LM-A to support umbilical EVA do not have to be made. These factors, as well as other operational considerations that enter the trade-off, will be treated after the capability of the PLSS to meet requirements is examined.

* These data on the EOP are approximate because of a recent change in requirements from 15 to 30 minute capability.

The Apollo PLSS is designed for lunar surface EVA. It contains closed-loop oxygen ventilation and LCG water circulation loops. Both loops pass through a heat exchanger, where heat is rejected by water sublimation. Water for sublimation is contained in a bladdered tank. The bladder is pressurized by the gas loop, and the volume between the bladder and the tank serves as a collector for water removed from the ventilating oxygen. The ventilation loop also contains a lithium hydroxide canister for CO_2 removal. Oxygen used in respiration and lost to leakage is made up from a primary oxygen supply. A two-way communication system for voice and data transmission is included. The power source is a 240 watt-hour primary battery. An emergency oxygen supply, the Oxygen Purge System (OPS), is worn with the PLSS. It is mounted on top of the PLSS. If, because of PLSS failure, the OPS is activated, it supplies oxygen for respiration, CO_2 washout, and ventilation cooling. The oxygen capacity of the OPS at 7500 psia is slightly less than that of the EOP (both are designed for 30 minutes emergency operation, but the OPS uses a metabolic rate of 1600 rather than 2000 BTU/hr). Unlike the EOP, the OPS requires manual activation. It contains a regulator, a battery and a heater, and its total charged weight is over three times that of the EOP.

The Apollo PLSS is limited to a metabolic mission of 4800 BTU total by the capacity of the LiOH canister and the oxygen supply. Enough water for removal of about 6000 BTU total through sublimation is provided because of the net environmental heat input on the lunar surface. (This environmental heating is due to the reflectivity of the lunar surface in the IR spectrum, and is not a factor in space where there is a net loss due to radiation.) The maximum ventilation rate at the suit pressure is 6 cubic feet/minute, which at 75% helmet mixing efficiency will handle a metabolic load of 1600 BTU/hr (from Figure 1). The PLSS is therefore limited to a 3 hour EVA at 1600 BTU/hr metabolic rate, and the average rate cannot exceed this level without buildup of the CO_2 level.

Three hours is the nominal period for each ATM two-man EVA, but the capability for a four-hour EVA has been a design requirement. One man will be doing most of the work, as the second is there as a safety observer. Sustained metabolic rates of the working astronaut between rest periods are expected to be upwards of 2500 BTU/hr, although the average for a whole ATM EVA will probably not exceed 2000 BTU/hr. An 8000 BTU total metabolic capability is therefore a realistic design requirement on a self-contained portable life support system for ATM EVA.

Comparing the design requirements of ATM EVA with the capability of the Apollo PLSS, the PLSS is shown to be deficient in both total metabolic capability (oxygen, lithium hydroxide, and water) and maximum ventilation rate. Use of an unmodified PLSS would result in restrictions on time and/or metabolic rates. It would have to be modified to meet design requirements. Further, both sublimator water fill and elimination of condensed water from the outside of the water tank bladder depend on gravity, and to reservice the PLSS in zero-g, other types of systems would be required for these operations. The PLSS has another disadvantage in that no cooling by the LCG water loop is possible between the time that the astronaut is suited and the time that the LM cabin is depressurized because water sublimation is required for heat rejection, and sublimation will not occur in a pressurized environment. In other words, the astronaut will be hot even before he starts the EVA.

The reservice requirements of a modified PLSS for each single 8000 BTU metabolic EVA would be 1.54 lbs of oxygen, 7.4 lbs of LiOH, approximately 9 lbs of water, and a 5.14 lb battery. Assuming that both PLSS's are launched charged, each would have to be reserviced three times, and the above requirements would be multiplied by six to find the requirements on the spacecraft for reservicing. Water and oxygen reservice capability exists in the Apollo LM, and there is apparently no reason that it cannot be retained in the LM-A, although some configuration changes might be required because of other mods, like the addition of the ATM Control and Display console.

The total oxygen that must be supplied to the LM-A cabin is not just the 9.4 pound PLSS reservice requirement because of the two-gas O_2/N_2 atmosphere in the cabin. To eliminate residual nitrogen from the astronaut's blood and from the suit ventilation loop, he must prebreath pure oxygen, and the suit must be purged with pure oxygen. The prebreathing requirement for four two-man EVA's is 6 pounds, and the suit purge requirement is approximately 15 pounds. The total requirement is therefore on the order of 30 pounds. It could be decreased to 21 lbs by reservicing the PLSS in the CM. The present Apollo LM Ascent Stage (A/S) oxygen storage capability is 4.4 pounds. Either the A/S storage capacity must be increased, or an interface between the A/S and the CM-SM cryogenic supply must be provided.

The water storage capacity of the Apollo LM A/S is not sufficient to provide cooling during unmanned rendezvous and docking, and a third A/S water tank must be added for this purpose. PLSS water reservicing requires a fourth tank. There is the possibility of reservicing the PLSS in the CM with fuel cell water, but a new tap would probably be required as the capability of the PLSS to operate on chlorinated water from the CM potable water tank is questionable.

It is clear that substantial modifications to the LM A/S, as well as the PLSS, are required to meet the design requirements of four two-man ATM EVA's using a self-contained portable life support system. The LM modifications required to support an umbilical EVA with the PCU are not that much more extensive, and this mode has been baselined. A high-pressure oxygen interface has been provided between the LM-A and the CM-SM cryo storage system to avoid storing large quantities of gaseous oxygen in the LM-A. This was mentioned above as one of the alternatives for satisfying the PLSS support requirements. With the PCU, high-pressure oxygen transfer is the clear choice because the open-loop oxygen ventilation system results in a total requirement of between 250 and 300 pounds (as opposed to 30 for the PLSS). An oxygen accumulator and regulator system similar to the one in the Airlock replace the LM A/S gaseous oxygen tanks. The major addition to the LM A/S to support umbilical EVA is the liquid cooling garment support section (LCGSS). Like the AM system, two loops are provided. However, the liquid-to-liquid heat exchangers connect the LCG water loops to water sublimators rather than the LM-A radiator loop. The requirement for water for sublimation is the same as in the case of PLSS recharge, as the total heat to be rejected is the same. However, the umbilical system provides cooling before the cabin is depressurized, and the astronaut does not have to store the heat generated until that time as he does when using a PLSS. The Apollo LM water supply module, which connects the four water storage tanks to the LCG sublimators, is unchanged.

The weight tradeoff between the two alternatives - PLSS vs PCU/umbilical - for ATM EVA results in a standoff. Small weight advantages can be shown for either system as a function of assumptions on metabolic rate, number of spares, and usability of IVA PCU's and umbilicals for EVA. Roughly, the oxygen penalty associated with the open-loop PCU is balanced by the heavier fixed weight of the PLSS and the LiOH and batteries for recharge. The PCU has a definite stowage volume advantage as the oxygen is stowed in the Service Module and the three cryo tanks have sufficient capacity to meet all requirements. Although difficult to quantify, the PCU will show a cost advantage. This is so because the PCU must be developed for AAP IVA and Airlock EVA in either case. The cost for modifying, qualifying, and purchasing a suitable PLSS and reserve capability in the spacecraft will run an estimated three million dollars more than the approximate two million dollar price tag for modifying the LM to support umbilical EVA.

Except for the umbilical management problem, the PCU has several operational advantages in that donning and system checkout are much simpler than in the case of the PLSS, and no resupplying is required.

From all considerations other than the umbilical management problem, it is apparent that the decision to use the PCU and umbilical for ATM EVA was the proper one. Before meaningful work can be done on the one operational problem, more knowledge on the specific nature and severity of the problem is required. This leads to the recommendation that planned neutral buoyancy tests of ATM EVA at MSFC be initiated as soon as possible. Results of these tests will lead to designs for umbilical restraint mechanisms and operational procedures to minimize the problem, or demonstrate that the problem is so severe that a self-contained portable life support system is the only practical solution. Until the latter is shown to be the case, which is definitely not expected, it would be an error to change the present baseline of umbilical EVA with the PCU.

OTHER OPTIONS FOR ATM-EVA

Drag-Through Umbilical

The suggestion that umbilicals from another module be pulled through the LM-A cabin to the EVA astronauts has been made. This might save some of the two-million dollar cost of the LM-A umbilical support systems.

In a coupled ATM mission, umbilicals could be connected to the AM support systems. However, the capability of the pumps in the AM LCG loops might have to be increased to maintain satisfactory water flow rates through the longer umbilical. As the MDA and the forward AM compartment would become part of the airlock that must be repressurized after each EVA, the total mission oxygen requirements exceed the total stowage capacity of the SM cryo tanks. This oxygen deficit could result in a decrease in the planned 56 day duration of the mission. The AM umbilical support systems will have previously been used in 28 and 56 day missions and subjected to two periods of space storage prior to the coupled ATM mission. It is preferable from a reliability standpoint to use almost identical, but new systems, particularly since EVA operations are essential for a successful ATM mission. Capability to use the AM systems as a backup should be retained, but in this case egress and ingress should be through the Airlock hatch rather than through the LM.

Decoupled ATM mission capability is a Program requirement, and the AM systems will not be available in this mission. If EVA umbilical support systems are not in the LM-A, they must be in the CM, and the CM would become part of the airlock that is depressurized before EVA and repressurized after EVA. All three men must therefore spend the entire EVA time in pressurized suits. This does not necessarily mean that oxygen use during EVA would increase by 50%, because the man in the CM can use the closed-loop ECS suit circuit, which provides sufficient ventilation cooling in view of his low metabolic rate. The additional oxygen requirement for CM repressurization is not a problem in the decoupled mission, because the total requirements are much less than those of the coupled mission for which the cryo tanks are sized.

To support two umbilical EVA astronauts from the CM, the oxygen delivery capability of the CM IVA station would have to be more than doubled, and a gaseous oxygen accumulator added. The accumulator must have the same capacity as the system now baselined for the LM-A, as the requirements are identical. Two liquid cooling garment support loops would have to be added. New liquid-to-liquid heat exchangers could transfer LCG heat directly to the CM-SM ECS radiator loop. The heat rejection capability of the existing radiators should be sufficient during the EVA period, because heat from the ECS loop is used to warm the high flow of oxygen from the SM cryogenic tanks. Presently, electrical heaters in the ECS loop must be in operation during high oxygen flow conditions to prevent the coolant from freezing. Coupling the LCG loops to the CM-SM radiator loop could thus save some electrical power during EVA. Use of a CM system during a coupled mission would add to the oxygen deficit, as the CM, MDA, and LM-A would all be part of the airlock that would have to be repressurized after each EVA. It seems doubtful that CM mods required to support umbilical EVA would cost appreciably less than the LM-A systems now baselined.

Umbilical support by LM-A systems will minimize operational requirements, permit a common CM ECS configuration for all AAP missions, and avoid an oxygen deficit in the coupled ATM mission. There should not be a significant cost difference between integrating these systems in the LM-A or in the CM. It is therefore recommended that the present baseline be retained, and that the drag-through umbilical concept not be further pursued.

Portable Environmental Control System

Only two portable life support systems, the PCU and the PLSS, have been considered in the trade-off for ATM EVA.

The PCU is a simple, open-loop system supported by an umbilical from the spacecraft that must be developed for earlier AAP missions. The PLSS is an existing Apollo self-contained, closed-loop system, which must be modified if used for the ATM EVA's. The next generation of the portable systems is the Portable Environmental Control System (PECS). It has not been considered because of the greater cost of both the system and the spacecraft mods required to support it.

The PECS can be operated either with or without an umbilical. Its self-contained metabolic capacity is 8000 BTU, sufficient for an ATM EVA with no umbilical. A water evaporator is the prime heat rejection source, and is linked to both the LCG water loop and the closed-loop oxygen ventilation loop. If a water umbilical is used, as it would have to be for IVA, a liquid-to-liquid heat exchanger replaces the evaporator as the heat rejection source. Oxygen is supplied by a self-contained, 7500 psia supply, or by an umbilical. A bypass valve in the oxygen supply line and a pressure relief valve in the oxygen return line permit open-loop ventilation. A battery is provided for power, and a transceiver for communications and biomedical data, although these functions can also be performed through an umbilical.

The PECS is under development at the AiResearch Division of the Garrett Corporation under OART contract. The end-item of the original contract was a prototype unit. AAP has agreed to supplement the funding to provide a unit that can be flight qualified. If the umbilical management problem during ATM EVA proves so severe that a self-contained system is required, the status of the PECS should be reviewed for its possible application. As the PECS can be used for IVA as well as EVA, the total portable system weight and volume on AAP-3/AAP-4 would be less than for both PCU's and modified PLSS's. Although the total cost to AAP would be higher, total cost to the Agency, considering future programs where the PECS will find application, will be less; there would be no requirement to modify and requalify the PLSS.

SUMMARY AND RECOMMENDATIONS

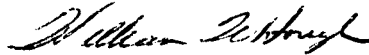
The Pressure Control Unit presently baselined for all AAP EVA and suited EVA, with support by an umbilical and a backup EVA oxygen supply, has been found to be the optimum system considering all factors. The reduced cost of a common system that meets all requirements, the minimum operational complexity, the least total stowage requirements, and the elimination of system recharge requirements all contribute to this conclusion. The only unresolved problem is that of umbilical management during ATM EVA from the LM-A. To resolve this problem, data from the

neutral bouyancy test program are required, and it is recommended that these tests be initiated at MSFC. If these tests demonstrate that the problem is so severe that a self-contained system is required, the application of the PECS rather than a modified PLSS should be considered.

The drag-through umbilical concept is not attractive, considering requirements for support of both coupled and decoupled ATM missions, and it is recommended that it not be pursued.

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1022-WWH-ms

Attachments
Figures 1/2

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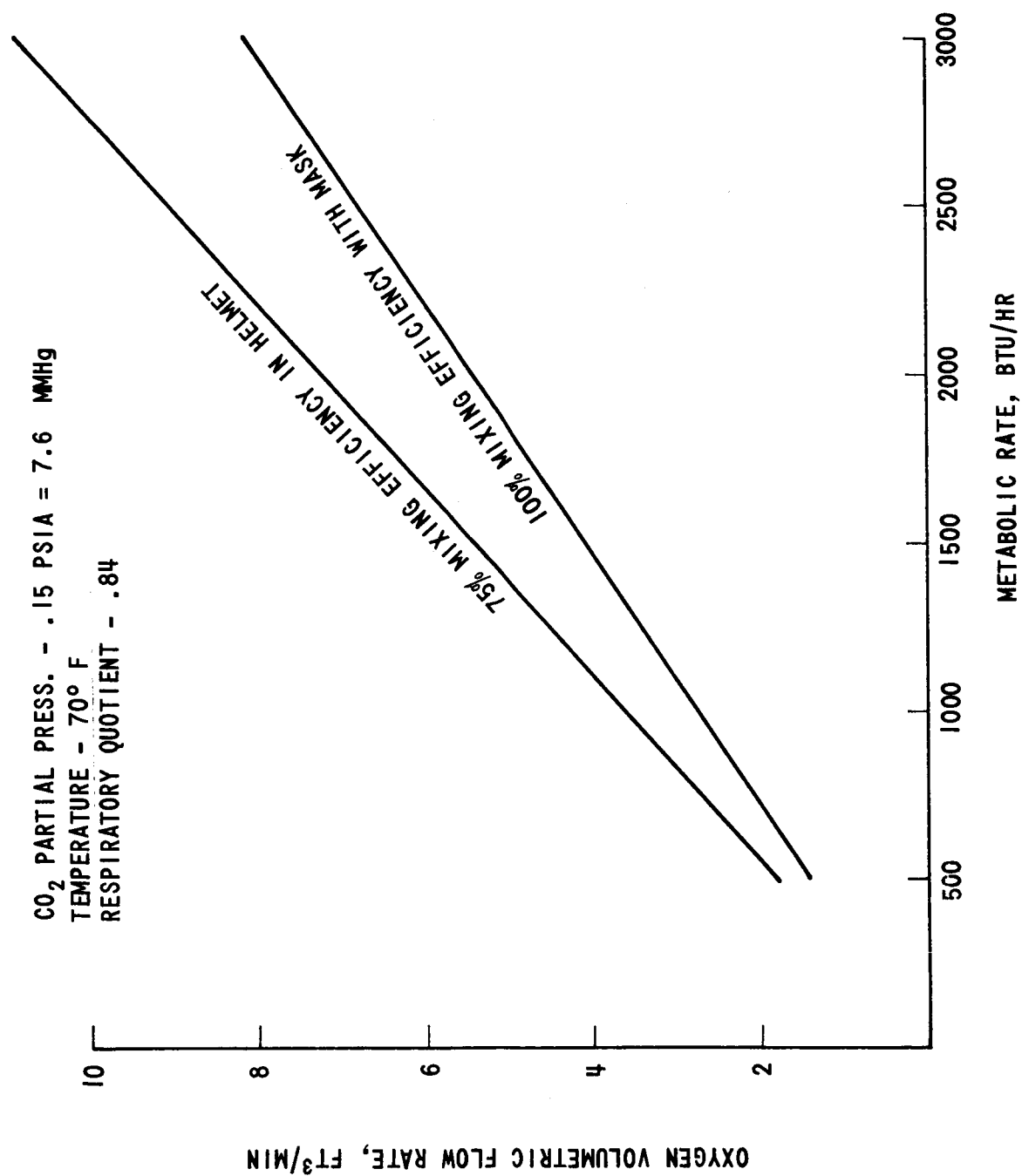
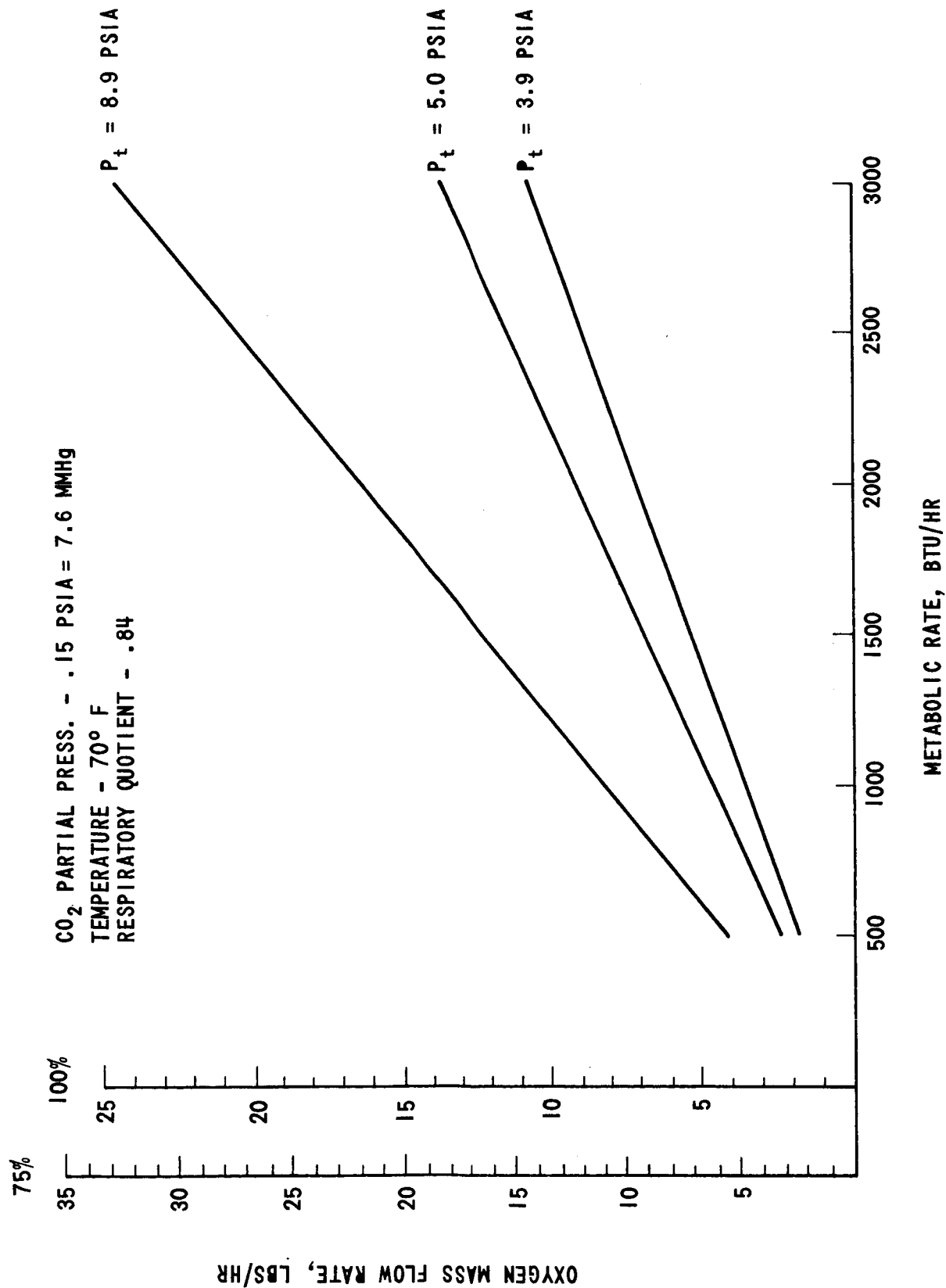


FIGURE 1 - VOLUMETRIC FLOW RATE OF VENTILATING OXYGEN VS. METABOLIC RATE

O₂-CO₂ MIXING EFFICIENCY



**FIGURE 2 - MASS FLOW RATE OF VENTILATING OXYGEN
 VS. METABOLIC RATE**